IS 6939 (1992): Methods for determination of evaporation from reservoirs [WRD 10: Reservoirs and Lakes]

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IS 6939 : 1992
(Reaffirmed 2002)

भारतीय मानक

जलाशय से वाष्पन ज्ञात करने की पद्धतियाँ

(पहला पुनरीक्षण)

Indian Standard

METHODS FOR DETERMINATION OF EVAPORATION FROM RESERVOIRS

(First Revision)

UDC 627·81 : 556·132·2

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

August 1992 **Price Group 4**

Reservoirs Sectional Committee, RVD 4

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Reservoirs Sectional Committee had been approved by the River Valley Division Council.

It is an established fact that sizable quantities of water are lost by evaporation from storage reservoirs. With the rapid increase in the developmental activities of the country, the need for conservation of stored water is keenly felt. The huge cost at which the storage reservoirs are built calls for minimizing evaporation to the maximum extent possible. The need for minimization of evaporation loss is even greater in the case of semi-arid and arid regions. Therefore, it is important to have a knowledge of the methods and formulae to evaluate evaporation loss, at the first instance.

Assistance has been derived from the valuable data supplied by the Indian Meteorological Department, in the formulation of this standard.

Mean monthly and annual evaporation using mesh covered fixed point gauge class 'A' pan evaporimeter with wire mesh (*see* IS 5973 : 1970) in respect of 40 departmental observatories for the period 1969-1975 and 72 agrometeorological observatories for the period 1966-1975 have been published by Indian Meteorological Department (I.M.D.) in the publication 'Evaporation Data of Observatories in India, 1980' and the same may be used wherever applicable.

This standard was first published in 1973. This revision has been taken up in the light of experience gained in the use of the standard during the last 18 years. The important changes effected in this revision include the following:

a) Effect of radiation and size of evaporation surface on the rate of evaporation,

b) Uniformity of notations used in various formulae, and

c) Updating of data in text and Fig. 1.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

METHODS FOR DETERMINATION OF EVAPORATION FROM RESERVOIRS

(First Revision)

1 SCOPE

This standard covers the methods for the determination of evaporation from reservoirs. It also provides certain empirical formulae for use in the absence of actual measurements.

2 REFERENCES

The following Indian Standard is a necessary adjunct to this standard:

IS No.	*Title*
5973 : 1970	Pan evaporimeter

3 TERMINOLOGY

3.1 For the purpose of this standard, the following definition of evaporation shall apply.

3.2 Evaporation

The process by which the water is changed from the liquid state to gaseous state below the boiling point through the transfer of heat and wind energy.

4 FACTORS AFFECTING EVAPORATION

4.0 The following are the major factors which influence the rate of evaporation:

a) Vapour pressure difference between the water surface and the layer of air just above,
b) Temperature of both water and air,
c) Radiation,
d) Wind,
e) Atmospheric pressure,
f) Quality of water,
g) Heat storage in the water body, and
h) Size of evaporation surface.

4.1 Vapour Pressure Difference Between the Water Surface and the Layer of Air Just Above

The rate at which molecules leave the water surface depends on the saturation vapour pressure of the air at the temperature of the water surface (e_s). Similarly the rate at which molecules enter the water depends on the saturation vapour pressure of the air at the dew point (e_d). The rate of evaporation, therefore, depends on the difference between the saturation vapour pressure of the air at the temperature of water surface and at the dew point. Evaporation is proportional to $e_s - e_d$ and continues until $e_s = e_d$.

4.2 Temperature of Both Water and Air

The rate of emission of molecules from water is a function of its temperature, the higher the temperature, the greater will be the energy of the molecules and the rate of emission. Experiments with heated water show that evaporation does increase with the temperature of the water surface. This is a direct result of the increase in vapour pressure with temperature.

4.3 Radiation

The net radiation available at the evaporating surface affects the rate of evaporation. Net radiation is either observed directly or estimated as difference of incoming short wave and outgoing long wave radiation. Though conditions of total incoming radiation per unit horizontal surface area at both lake and pan sites may remain same, there would be differences in the outgoing fluxes at these two water surfaces. The albedo of the two surfaces may not differ greatly but the pan bottom would reflect appreciable amount of short wave radiation. Moreover, because of different degrees of roughness of the two water surfaces and also the influence of the metal pan itself, the net radiation received would differ.

4.4 Wind

Since turbulence varies with wind speed, there should necessarily be a relation between evaporation and wind movement. Experimental data do not disclose the exact nature of this relation. It is commonly believed that the effect of increasing wind speed decreases as some high value is approached. The effect probably depends on surface roughness and the dimensions of the water body.

4.5 Atmospheric Pressure

Atmospheric pressure is so closely related to other factors affecting evaporation that it is practically impossible to study the effect of its variation in isolation. The number of air molecules per unit volume increases with pressure. Consequently, with high pressure there is more chance that vapour molecules escaping from the water surface will collide with an air molecule and rebound into the liquid. Evaporation would be expected to decrease with increasing pressure and *vice versa*. Changes in other meteorological factors accompanying pressure changes at a station generally conceal the effect of pressure. The reduction in pressure with increase in elevation acts to increase evaporation at high elevations. This effect is offset by the general decrease in temperature with elevation and hence the relation between elevation and evaporation is not clearly defined.

4.6 Quality of Water

Turbidity of water decreases the rate of evaporation. The rate of evaporation is less for salt water than for fresh water and decreases as the specific gravity increases. The evaporation rate decreases about one percent for each one percent increase in specific gravity until crusting takes place, usually at a specific gravity of about 1.30. Evaporation from sea water has been estimated to be about 2 to 3 percent less than from fresh water when other conditions are the same.

4.7 Heat Storage in the Water Body

For water bodies of shallow depth the amount of heat storage is negligible. In deep water bodies, however, the heat storage is considerable. A portion of the radiation energy received in summer is stored in the water and is returned later during winter. Therefore, for an equal quantity of radiation received the amount of evaporation will be less in summer and more in winter. Overall effect of heat storage on evaporation in a year may not be appreciable. As such, heat storage reflects appreciably on the monthly rates of evaporation in case of deep water bodies.

4.8 Size of Evaporation Surface

The size/area of the evaporating surface affects the rate of evaporation because the air mass is modified by humidification as it travels over water surface causing variation of air and water temperature as well as of wind and humidity over the evaporating surface. The degree of this modification depends on wind speed, initial moisture content of the air mass and the stability of the atmosphere.

5 METHODS OF DETERMINING EVAPORATION FROM FREE WATER SURFACES

5.0 The following methods are in use to determine the rate of evaporation from open water surfaces:

a) Water budget or storage equation method,
b) Mass (vapour) transfer method,
c) Energy budget or insolation method,
d) Measurement in an auxiliary pan (or tank) and correlate pan evaporation to natural water surface evaporation, and
e) Empirical formulae and graphical methods.

5.0.1 Of the above methods, (a), (b) and (c) call for determination of parameters which are difficult to assess while the pan measurements and the graphical methods have the advantage of simplicity.

5.1 Water Budget or Storage Equation Method

This method involves the equation:

$$E = P + I - O \pm U \pm \Delta S$$

where

E = evaporation;
P = precipitation on the water surface;
I = surface inflow;
O = surface outflow;
U = underground inflow or outflow into or from the reservoir; and
ΔS = change in storage, which is negative for increase in storage and positive for decrease in storage.

5.1.1 The quantities are usually expressed in millimetres depth of the water area for some convenient time interval.

5.1.2 The limitation of the method is that it is difficult to determine these quantities with sufficient accuracy. All these errors in measurement are reflected in the resulting value of E. It is particularly difficult to make an accurate assessment of the ground-water flow. The application of the method may be limited to those reservoir sites whose seepage inflow and outflow are small compared to evaporation.

5.2 Mass (Vapour) Transfer Method

5.2.0 This method is based on the assumptions given in **5.2.1**.

5.2.1 If a moisture gradient exists in the air, it uses the basic flux-gradient relationship of any atmospheric property whose average concentration also varies with height and gives water vapour transport as:

$$E = \rho Kw \frac{dq}{dz}$$

where

E = evaporation in mm ;
ρ = air density in g/cc ;
Kw = eddy transfer coefficient for water vapour ;
q = specific humidity ;
z = height in metres; and
$\frac{dq}{dz}$ = may be derived from two observations at different heights above the water surface.

5.2.2 In practice *Kw* is assumed to be equal to *Km* (the eddy transfer coefficient for momentum). *Km* is determined from measurement of changes in wind speed with height. Assumption of a logarithmic form of wind profile leads to the classical expression of Thornthwaite and Holzman for evaporation from aerodynamically smooth surfaces involving wind speed and humidity measurements at two heights, namely:

$$E = \frac{-10 K^2 \rho (q_2 - q_1)(u_2 - u_1)}{[\log_e (z_2/z_1)]^2}$$

where

E = evaporation in mm;
K = Von Karman's constant = 0.41;
ρ = air density in g/cc;

q_2, q_1 = specific humidities at heights z_2 and z_1 which may be 2 m and 1 m respectively above the water surface; and

u_2, u_1 = wind speeds in cm/s at heights z_2 and z_1.

5.2.3 The rate of movement of the water vapour is accentuated by the intensity of turbulence in the air. The humidity gradient may be determined from simultaneous measurement of moisture content of the air at the same two elevations above the surface with suitable, sensitive hygrometers as determination of the gradient of wind velocity requires the use of sensitive anemometers with low starting speeds (< 0.1 m/s) and which may register a 66 percent response to an instantaneous change in wind speed before an air travel of 1 m past the anemometer cups.

5.3 Energy Budget Method

5.3.0 This method of determining evaporation is based on the law of conservation of energy. For any given body of water a balance should exist between:

a) insolation or net radiation;
b) heat transferred from the water surface by radiation, conduction or convection;
c) heat energy acquired or lost in raising or lowering the temperature of water; and
d) heat dissipated or acquired by evaporation or condensation.

5.3.1 The energy budget equation is as given below:

$$R = H + LE + G$$

where

R = net radiation flux received at the surface in cal/cm^2 measured by a net radiometer;

H = sensible heat flux in cal/cm^2;

LE = latent heat flux, where L is the latent heat of vaporization in cal/g, and E is evaporation in mm; and

G = heat flux in the soil or water in cal/cm^2.

As H is generally difficult to determine, Bowen ratio $\beta = \frac{H}{LE}$ may be evaluated from the following equation:

$$\beta = \frac{Ts - T}{e_s - e} \times 0.61 \times \frac{P}{1\,000}$$

where

Ts = water surface temperature in ^{0}C;

T = air temperature in ^{0}C;

e_s = saturation vapour pressure at Ts in hectopascal (hpa);

e = vapour pressure of air at T in hpa; and

P = station level pressure in hpa.

And now evaporation E may be computed from

$$E = \frac{R - G}{L} \left(\frac{1}{1 + \beta} \right)$$

5.4 Measurement from Pans and Lakes

The loss of water by evaporation from pans/lakes has been found to depend on, among other factors, the size of pan/tank. As hydrologists and irrigation engineers desire to have evaporation from natural water surfaces, it is necessary to determine a conversion factor/coefficient for converting evaporation measured from pan to evaporation from a free water surface/reservoir. It has been found that these coefficients differ from pan to pan depending on their sizes, all other conditions being same. Experiments have shown that a limiting value of evaporation is reached where the diameter of the pan/tank approaches about 4.6 m.

5.5 Empirical Formulae and Graphical Methods

5.5.0 Evaporation is expressed as a function of various atmospheric elements, such as temperature, pressure, humidity and wind speed in many empirical formulae based on observation of evaporation from pans, reservoirs and lakes.

5.5.1 Many experimenters have tried to improve on the empirical approach of Dalton, which considers the bulk transfer of water vapour from surface to air as occurring along the gradient of vapour concentration with an intensity which may simply be related to the prevailing wind speed. The formula is as given below:

$$E = f(u)\,(e_s - e)$$

where

E = evaporation;

$f(u)$ = an empirically derived function of wind speed commonly given in the form; and

$f(u)$ = $a + bu$ or $a(l + bu)$ or cu.

where a, b and c are constants;

e_s = saturation vapour pressure at water surface temperature; and

e = vapour pressure of overlying air.

5.5.2 The variations in the mass transfer coefficient, namely, $E/cu\ (e_s - e)$ are seen to be related to the surface area (A) of the reservoir. The formula is as given below:

$$E = 0.0291\, A^{-0.05}\, cu\,(e_s - e)$$

where E is in mm/day, A in m^2, u in m/s at 2 m above the surface and e_s and e are in hpa.

5.5.3 The difference between the above formulae lie in the constants which may be due to the observer, the locality or the means and methods of measurement employed or a combination of these.

5.5.4 Many nomograms or graphical methods are also in vogue for easy computation of evaporation from free water surfaces. The most widely used nomograms, that is, Kohler's co-axial technique has been described in **11.2**.

6 PAN EVAPORIMETERS

6.0 For measurement of evaporation many types of pans are used. Among them the following are more widely used:

a) Class A Pan (Modified);
b) Class A US Weather Bureau Land Pan;
c) Class A US Weather Bureau Floating Pan;
d) Colorado Sunken Pan;
e) US Weather Bureau of Plant Industry Sunken Pan;
f) GGI-3000 Pan (Russian); and
g) US Geological Survey Floating Pan.

6.0.1 A cylindrical tank of surface area 20 m^2 and depth 2 m (Russian) which is claimed to give shallow lake evaporation is also in use at some places.

6.1 Class A Pan (Modified)

6.1.1 The equipment consists of a large cylindrical pan, 1 220 mm in diameter and 255 mm deep, made from 20 gauge (0.914 mm) copper sheet, tinned inside and painted white outside (*see* Fig. 1C). A stilling well provides an undisturbed water surface around the point of the fixed point gauge by breaking any ripples that may be present in the main part of the pan. It consists of a brass cylinder mounted on a heavy circular base, which ensures that its position in the pan is not affected by the wind. Three small openings along the circumference of the cylinder 120° apart near the base, permit the flow of water from or into the stilling well end and at the same time restrict surging action of water at the point of measurement. The reference point is provided by the brass rod, fixed at the centre of the stilling well and tapered to end in a point, exactly 190 mm above the base of the pan. The pan rests on white-painted wooden stand which ensures that the bottom of the pan is above the level of surface water in rainy weather. It is covered with wire netting of standard mesh in order that loss of water from the pan due to extraneous agents such as birds and animals may be avoided. A thermometer to measure surface temperature of the water is fixed with a clamp to the side of the pan so that the bulb dips 50 mm below the water surface.

6.1.2 The graduated measuring cylinder to pour the water into the pan is a brass container with a scale 0-200 engraved inside it, along its length. It has a diameter exactly one-tenth of the pan, namely, 122 mm so that the cross sectional area of the cylinder is one-hundredth that of the pan. Thus 200 mm of water from the cylinder added to the pan will raise the level of water in the pan by 2 mm. Each small division of scale corresponds to 10 mm, and the level of water in the pan can, therefore, be measured correct to 0.1 mm. Since the capacity of the cylinder is only 200 mm, the cylinder has to be filled more than once if over 2 mm of water is lost by evaporation from the pan during the interval between two observations (*see also* IS 5973 : 1970).

6.1.3 Evaporation observations are taken thrice a day at 0830, 1400 and 1730 hrs IST.

6.2 Class A US Weather Bureau Land Pan

This pan is circular, 1 207 mm in diameter and 254 mm deep, mounted on a wooden open platform on the ground (*see* Fig. 1A). It is constructed of galvanized iron or monel metal, preferably the latter where corrosion is a problem. The pan is filled within 51 mm of the rim. Evaporation measurements are made by hook gauge or refilling to a fixed point (*see also* **6.1**)

6.3 Class A US Weather Bureau Floating Pan

6.3.1 The land pan USWB Class A type (*see* Fig. 1B) used as floating pan, will have water level inside the pan 75 mm below the top of the pan. The water surface inside the pan is kept at the same level as that of outside. Surging in the pan may be reduced by perforated baffle plates or screens, below the water line and the pan is surrounded by a raft to protect it from waves.

6.3.2 The amount of evaporation is determined by the quantity of water required to bring the water level up to a fixed index point in the centre of the pan.

6.3.3 Being located in water, this type of pan is not affected by drifting soil and snow, and is subjected to conditions which are very similar to those over and in the lake or reservoir. This type of pan is, however, subject to splashing during high winds and is less accessible for measurement than a land pan.

6.4 Colorado Sunken Pan

The pan is 914 mm square and 457 mm deep made up of galvanized iron, and is set in the ground with the rim 51 mm above the ground level (*see* Fig. 1D). The water level is maintained at or slightly below the ground lelvel. A hook gauge or the fixed point gauge is used for measurement.

6.5 US Weather Bureau of Plant Industry Sunken Pan

The pan is 1 829 mm in diameter and 610 mm deep made of galvanized iron (*see* Fig. 1E). It is installed in the ground with rim 102 mm above the ground level. The water level in the pan is maintained at approximately the surrounding ground level.

6.6 GGI-3000 Pan (Russian)

This pan is a cylindrical tank with a conical base made of galvanized sheet of iron. The diameter is 618 mm (surface area 0.3 m^2), the depth is 600 mm at the wall of the tank and 685 mm at the centre (*see* Fig. 1F). The tank is sunk in the ground with the rim approximately 75 mm above. A similar sunken tank with a funnel is installed alongside for measurement of precipitation. Sometimes pans of same dimensions both for measurement of evaporation and precipitation and mounted above the ground are used.

6.7 US Geological Survey Floating Pan

Since it is likely that the evaporation from a pan floating in a large body of water would be very nearly the same as from the surrounding water, the US Geological Survey has used a pan 900 x 900 x 450 mm deep supported by drum floats in centre of raft 4.25 x 4.87 m. The water level in the pan is supposed to be at the same elevation as that of the surrounding body, with the sides of the pan projecting 75 mm above.

7 MERITS AND DEMERITS OF DIFFERENT PANS

7.1 The disadvantages frequently cited for sunken pans are:

a) It is difficult to detect leaks,
b) They tend to gather dirt and debris since they are close to the ground,
c) They are difficult to clean, and
d) Extra care required to maintain the surroundings since tall grass could significantly affect wind movement over the pan.

7.2 The main advantage claimed for sunken pans is that the aerodynamic and radiation characteristics are approximately same as of a lake.

7.3 Tanks above ground are cheaper and easier to install. Detection of leaks and emptying the tanks for cleaning are also simple. The main objection to their use is the possibility that the pan might be subjected to radiation on the sides and bottom.

7.4 Difficulties in measurement and frequent splashing are some of the disadvantages of the floating pans.

7.5 Of the pans mentioned, Class A pan (modified) used at network of stations in India (*see* Fig. 1C) should be preferred.

8 LOCATION OF EVAPORATION STATIONS

8.1 The following are the recommendations of the World Meteorological Organization regarding minimum network of evaporation stations:

a) Arid regions — One station for every 30 000 km^2,
b) Humid temperate regions — One station for every 50 000 km^2, and
c) Cold regions — One station for every 100 000 km^2.

8.2 The object of a network is to ensure that the average and extreme values of a parameter at any point in the region covered by the network are obtained with sufficient accuracy by interpolation of data of the stations in the network. Evaporation values from pans show small areal and time variations. As pan evaporation data has to be meteorological processed to obtain estimates of evaporation from a natural surface, the evaporimeter is required to be located in a meteorological station only.

8.2.1 On the basis of **8.2** the following network of stations are suggested:

a) Base stations, one in each typical climatic regime making uninterrupted observations, and
b) Auxiliary stations to cover pedological and hydrogeological areas which are different from the base stations and recording observations for not less than five and not more than ten years.

8.2.2 The auxiliary set up should suffice to meet the hydrological needs of evaporation and evapotranspiration stations.

8.3 The recorded data of evaporation available for a period of five to ten years for a large number of stations may be used to fix up the number and distribution of the base stations. Data from stations already functioning should be periodically reviewed so that suspect stations with poor location and exposure conditions are discontinued when fresh observations from new stations nearby show them to be unrepresentative.

8.4 The site for records of pan evaporation and associated meteorological observations should, as far as possible, be so chosen that it is representative of the principal agricultural soil of the areas and is fairly level and open with no obstruction casting any shadow on the pan except during sunrise and sunset. Trees, buildings, etc, should not be closer to the site than ten times their height. Where radiation or sunshine observations are envisaged there should be no substantial objects to the East or West subtending an elevation angle of more than 3° with respect to the level of the radiation instrument or sunshine recorder. Poles or masts of small diameter would be an exception. The highest ground water level at the site should not be less than 2 m from the surface and the site should be free of flooding or water logging even during heavy rains. If the site is near a reservoir or lake, the evaporimeter enclosure should be located upwind of the reservoir along the most prevalent direction of the high winds and at a distance away from drifts of spray from the spillways. In wooded areas, the site should be free of the influence of trees. In mountaineous areas, the site should be on an open plateau or terrace. In areas of drifting sand, the site should be at a place with minimum drift and should be consolidated before the evaporimeter installation. When alternate sites are available, final selection should be governed by considerations, such as proximity to a source of water for cleaning and daily filling up of the evaporimeter and the convenience to the observer and proximity to his place of residence.

9 COEFFICIENTS FOR EVAPORATION PANS

9.1 The ratio of evaporation from a free water surface to that from an adjacent pan is known as the Pan-Coefficient. As already mentioned under **5.4** these coefficients differ from pan to pan.

9.2 The coefficients for different pans in use are given below:

a) US Class A Pan — 0.7;
b) Colorado Sunken Pan — 0.89;
c) US Weather Bureau of Plant Industry Sunken Pan — 0.93;
d) GGI-3000 Pan — varies from 0.75 to 1.00;
e) Class A Pan (Modified), being used in India — The ratio is found to vary between 1.10 and 0.90 for lake evaporation of the order of 4 to 5 mm/day and between 0.75 and 0.65 for lake evaporation of the order of 10 mm/day. The ratio is about 0.8 for transition months; and
f) US Geological Survey Floating Pan — 0.8.

9.2.1 These coefficients are valid on an annual basis only for reservoirs and that the monthly estimates, which refer to an extensive shallow sheet of water, have to be corrected for energy storage or advection into or out of the reservoir.

NOTE — The coefficients for (a) to (d) above are based on WMO Technical Note No. 83. The coefficients for (e) are based on the paper 'The role of mesh covered Class A pan in the extrapolation of evapo-transpiration estimates' by M Gangopadhyaya, S. Venkataraman & V. Krishnamurthy of ICAR symposium on 'Soil Water Management', Hissar, March 1969. The coefficient for (f) is based on transactions of American Society of Civil Engineers, Vol 99, 1934.

10 DATA AND EQUIPMENT REQUIRED FOR THE USE OF EMPIRICAL FORMULAE

For adopting empirical formulae, in the absence of any other method explained, observation of meteorological factors is quite essential. Information is required on temperature and humidity of air, temperature of water and wind velocity.

11 EVAPORATION FORMULAE AND GRAPHICAL TECHNIQUE

11.1 Some of the important formulae used for computing evaporation from pan/free water surfaces are:

a) Carl Rohwer's formula,
b) Penman's formula, and
c) Slatyer and Mcilroy formula.

11.1.1 *Carl Rohwer's Formula*

$$E = 0.075\,(1.465 - 0.000\,594p)\,(0.44 + 0.0\,733u)\,(e_s - e_d) \text{ and}$$

$$E_1 = 0.771\,E$$

where

E = pan evaporation in mm,
E_1 = lake evaporation in mm,
p = atmospheric pressure in hpa,
u = wind speed in km/h,
e_s = saturation vapour pressure of air at water surface temperature in hpa, and
e_d = saturation vapour pressure of air at dew point temperature in hpa.

11.1.2 *Penman's Formula*

$$E_1 = \frac{\gamma\, Ea + R\,\Delta a}{\gamma + \Delta a}$$

$$Ea = 0.263\,(ea - e)\,(0.5 + 0.0\,062\,u_2) \text{ and}$$

$$R = \mathrm{R_0}\,(1 - r)\,(0.18 + 0.55\,n/N) - \sigma\, Tm^4\,(0.56 - 0.092\sqrt{\mathrm{e}})\,(0.10 + 0.90\,n/N)$$

where

E_1 = evaporation in mm;
γ = psychrometric constant = 0.27;
Ea = aerodynamic term;
Δa = slope of vapour pressure curve at mean air temperature;
R = net radiation;
R_0 = mean extra-terrestrial radiation in evaporation unit (mm);
r = reflection coefficient of the evaporating surface;
n = actual hours of sun shine;
N = maximum possible hours of sun shine
σ = Stefan-Boltzman constant;
T_m = mean air temperature (absolute);
e = vapour pressure of air in hpa;
ea = saturation vapour pressure at air temperature in hpa; and
u_2 = wind velocity in km/day at height 2 m.

11.1.3 *Slatyer and Mcilroy Formula*

$$E_1 = \frac{S}{L}\,(R - G) + \frac{h}{L}\,(D - D_0)\,;$$

$$S = \frac{s}{s + t}\,; \qquad s = \frac{0.63}{p}\Delta W$$

where

E_1 = evaporation in mm;
S = slowly varying function depending on temperature;
t = 0.42 mg/g per degree celcius;
p = atmospheric pressure in hpa;
Δw = slope of the saturation vapour pressure curve at mean wet bulb temperature in hpa per degree celcius;
L = latent heat of vaporization in cal/g;
R = net radiation in cal/cm^2;
G = soil heat flux in cal/cm^2;
h = transfer coefficient depending on wind speed;
D = wet bulb depression at height z ; and
D_0 = wet bulb depression at zero level.

11.2 Graphical Technique

The most widely used graphical technique is Kohler's co-axial technique. This uses the mean air temperature, dew point temperature, wind velocity and radiation to obtain evaporation from free water surface.

Referring to Fig. 2A, knowing the mean daily air temperature proceed horizontally to the corresponding mean daily dew point temperature (or the vapour pressure difference), and then proceed downward to the corresponding wind velocity and from this point proceed horizontally to obtain *Ea*, the value of daily pan evaporation assuming watersurface temperature to be equal to the air temperature. Referring to right hand top portion of Fig. 2B, proceed from the mean daily air temperature horizontally to the corresponding solar radiation value (Langleys) and from this point proceed downwards till the actual value of *Ea* (calculated from Fig. 2A) is reached. From this point proceed horizontally to the left hand quadrant of Fig. 2B till the mean daily temperature is reached and then proceed downwards to obtain the daily lake evaporation. The procedure is indicated by arrows in Fig. 2. In this process we will be able to find out the product of net radiation exchange *Qn* and the slope of the vapour pressure curve at the air temepratute, besides the factor γ used in the Bowen's ratio by the use of the graph in the right hand lower quadrant of Fig. 2B.

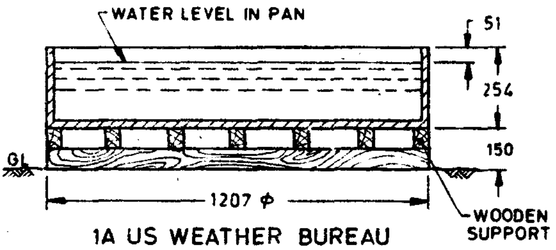
12 MERITS AND DEMERITS OF VARIOUS EVAPORATION FORMULAE AND GRAPHICAL TECHNIQUE

12.1 Formulae

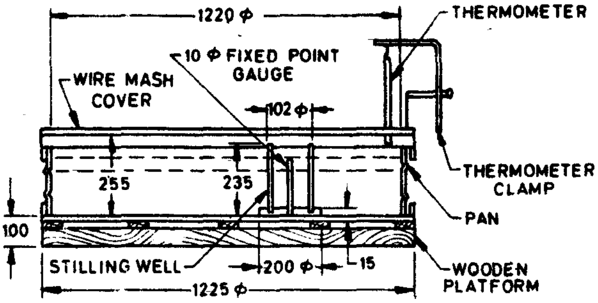
Carl Rohwer's formula was found to give inaccurate values where evaporation rates exceed 6 mm/day. The formulae combining both aerodynamic and energy balance equations are reliable and widely used wherever data on relevant parameters are available (Penman, Slatyer and Mcilroy).

12.2 Graphical Technique

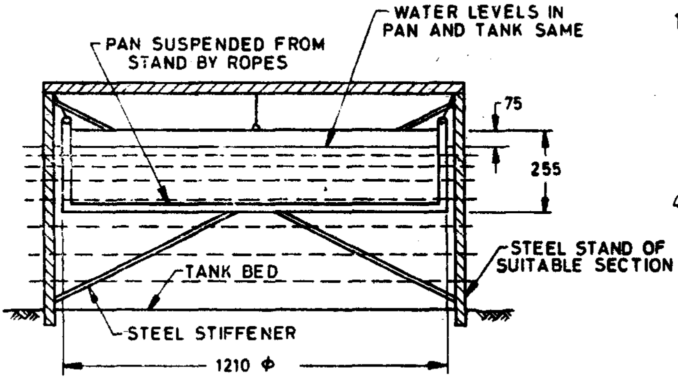
Kohler's co-axial technique has been used successfully in USA. In India also it is found to yield fairly reliable results.



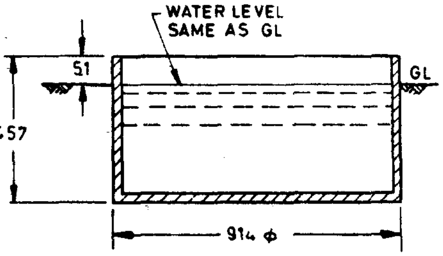
1A US WEATHER BUREAU CLASS A PAN



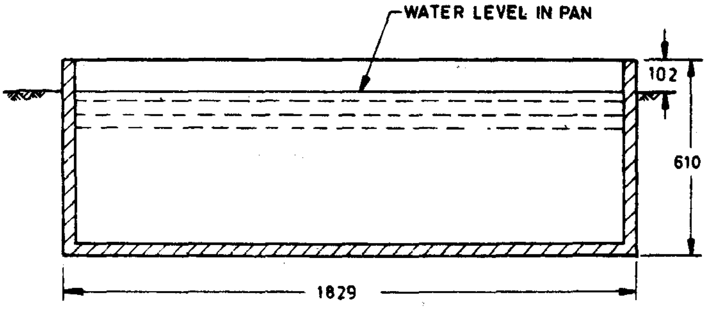
1C CLASS A PAN (MODIFIED)



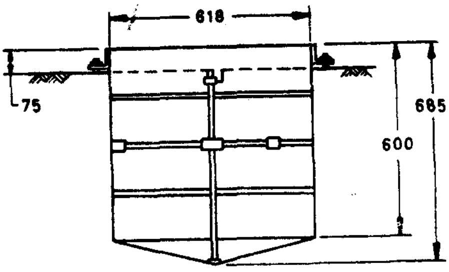
1B US WEATHER BUREAU CLASS A FLOATING PAN



1D COLORADO SUNKEN PAN



1E US WEATHER BUREAU OF PLANT INDUSTRY SUNKEN PAN



1F GGI-3000 PAN (RUSSIAN)

All dimensions in millimetres.

FIG. 1 EVAPORATION PANS

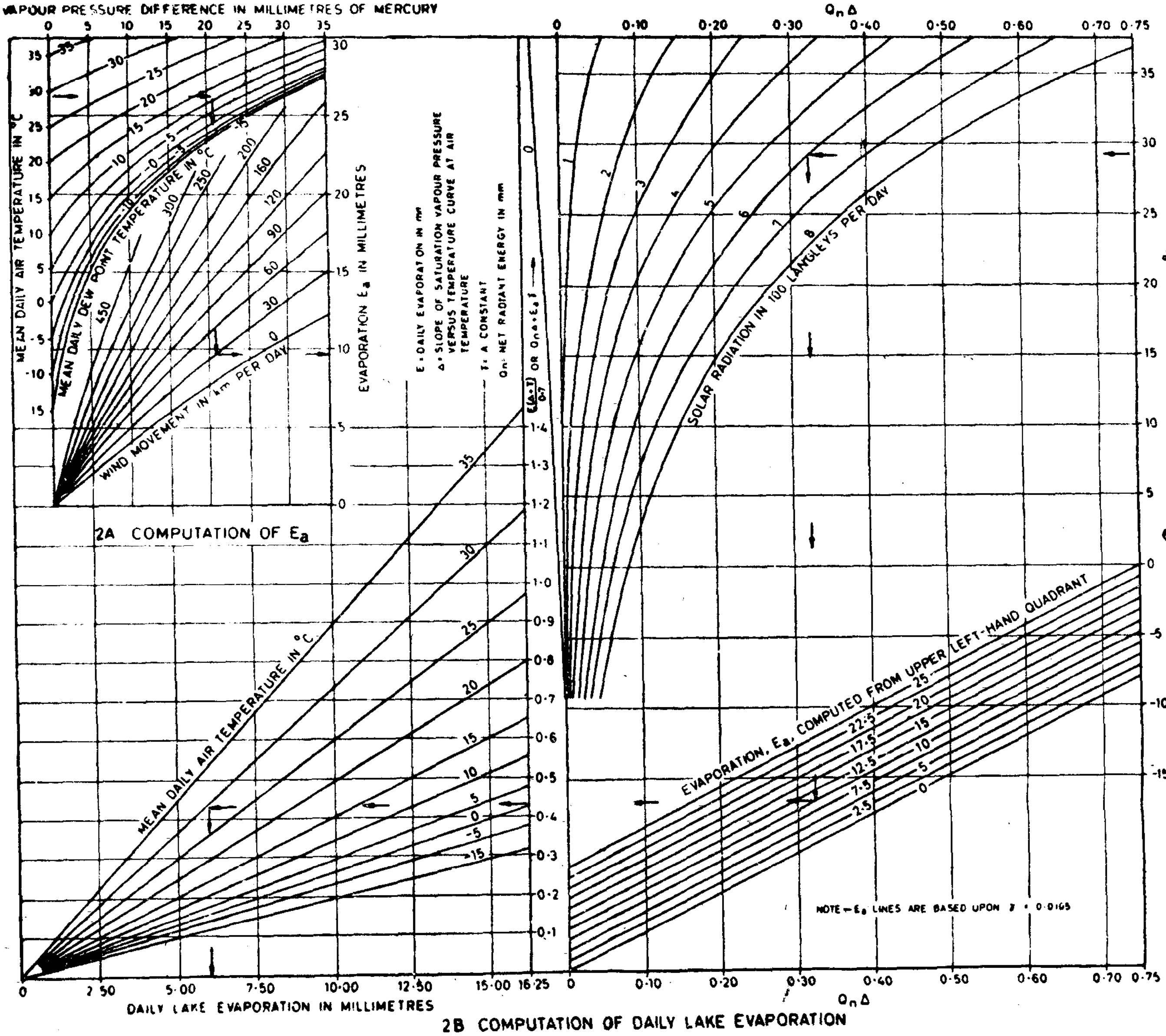


FIG. 2 KOHLER'S CO-AXIAL TECHNIQUE

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Printed at Printrade, New Delhi, India